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EVALUATION OF DIFFERENT SETS OF POST RAINY SORGHUM [*SORGHUM BICOLOR* L. MOENCH] CROSSES FOR YIELD AND RELATED TRAITS UNDER RAINFED SITUATION

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ABSTRACT:
Post-rainy season sorghum (Sorghum bicolor [L.] Moench) requires broadening of its genetic base to improve productivity while retaining adaptation to moisture-limited production environments. Conventional biparental breeding can restrict recombination among diverse favourable alleles, whereas multi-parent crossing provides greater scope for generating novel genetic combinations and transgressive variation. The present study evaluated 74 cross-derived entries, comprising 48 multi-parent-derived entries and 26 entries representing diverse conventional genetic backgrounds, under post-rainy season conditions at the ICAR–Indian Institute of Millets Research, Regional Station, Solapur, India. The material was assessed for nine quantitative traits encompassing flowering time, plant architecture, panicle characteristics, grain yield, stover yield and seed weight. Analysis of variance revealed highly significant differences ($P < 0.001$) among entries for all traits, demonstrating substantial exploitable variation within the evaluated breeding material. Days to 50% flowering ranged from 56.50 to 84.50 days, while grain yield per plant and stover yield per plant varied from 25.00 to 96.55 g and 29.00 to 115.00 g, respectively. Multi-parent-derived entries recorded comparatively higher mean grain yield (49.94 g plant^{-1}) than the M35-1 (41.62 g plant^{-1}) and CSV 26R (36.56 g plant^{-1}) background groups. MC-28 emerged as the most promising entry, recording the highest observed plant height (294.00 cm), grain yield (96.55 g plant^{-1}), stover yield (115.00 g plant^{-1}) and 1000-seed weight (40.60 g). Grain yield showed a strong positive association with 1000-seed weight at both phenotypic (P = 0.43) and genotypic (G = 0.52) levels, while stover yield was positively associated with grain yield (P = 0.43; G = 0.42). Genetic variability estimates further indicated exploitable variation for yield and adaptive traits. Overall, the study demonstrates the value of multi-parent-derived material for generating diverse and potentially superior post-rainy sorghum germplasm and identifies MC-28 as a promising breeding resource for further evaluation. Multi-environment testing, genotype × environment analysis and targeted stress-response characterization are warranted to establish the stability and broader breeding value of the identified entries.

KEYWORDS: Sorghum bicolor; post-rainy sorghum; multi-parent breeding; genetic variability; grain yield; stover yield; seed weight; rainfed conditions

INTRODUCTION

Sorghum (Sorghum bicolor [L.] Moench; $2n = 2x = 20$) is an important C_4 cereal valued for grain, fodder and biomass production and its adaptation to hot, dry and water-limited environments. Its climate resilience and relatively low resource requirement make it particularly important for food and livelihood security in semi-arid regions of Africa and Asia (Reddy and Reddy, 2019; Mundia et al., 2019). In India, sorghum is cultivated in distinct rainy-season (kharif) and post-rainy-season (rabi) environments that differ markedly in temperature, moisture availability and cultivar adaptation. Post-rainy sorghum is predominantly grown on residual soil moisture and consequently experiences progressive moisture depletion and terminal drought during crop development (Kholová et al., 2013). The predominance of locally adapted material, including M35-1, further emphasizes the importance of combining productivity with adaptation, grain quality and biomass production (Kaliamoorthy et al., 2024). Genetic variation for drought response, water-use traits and productivity in post-rainy sorghum provides opportunities to develop genotypes better suited to this environment (Patroti et al., 2021).

Conventional sorghum improvement has relied largely on biparental crossing, selection and heterosis breeding. Although these approaches have contributed substantially to productivity improvement, the use of relatively narrow parental combinations can restrict the range of favourable alleles available for selection. Combining ability and heterosis studies remain important for identifying superior parental combinations and hybrids for grain yield and associated traits in post-rainy sorghum (Vhanamane et al., 2026). However, broadening the genetic base remains essential for improving complex traits involving yield, biomass and environmental adaptation (Bailey-Serres et al., 2019; Hunter et al., 2017).

Multi-parent breeding provides an effective strategy for increasing genetic diversity and recombination by combining contributions from several founder parents. Compared with conventional biparental populations, such populations provide greater opportunities for generating novel allele combinations and favourable recombinants (Cavanagh et al., 2008; Rakshit et al., 2012). Structured multi-parent advanced generation inter-cross (MAGIC) populations further facilitate recombination among diverse founder genomes and have demonstrated value for genetic dissection and crop improvement (Ongom and Ejeta, 2018; Arrones et al., 2020).

The value of this approach has also been demonstrated in sorghum. Multi-parent populations have captured substantial genetic diversity and useful variation for complex agronomic traits, supporting their application in sorghum improvement (Kumar et al., 2023). Landraces provide an additional source of locally adapted and underutilized variation for productivity and stress adaptation (Kumar et al., 2022). Similarly, sorghum × maize derivatives can contribute novel variation and useful biomass-related attributes to sorghum breeding programmes (Visarada et al., 2017). Thus, combining diverse breeding materials rather than relying on a single parental source can expand the opportunity to recover favourable trait combinations (Scott et al., 2020).

Recent work has provided direct evidence for the relevance of this strategy in post-rainy sorghum. Patroti et al. (2025) developed advanced derivatives through an eight-parent crossing strategy and demonstrated superior grain and stover productivity together with favourable drought and biotic-stress responses. Their study showed that eight-way cross-derived lines could outperform two-way and four-way derivatives as well as founder parents, demonstrating the potential of multi-parent recombination to generate productive and stress-resilient post-rainy sorghum material. However, the relative performance of different categories of cross-derived material under a common post-rainy, rainfed environment remains insufficiently characterized. A comparative assessment of sorghum × maize derivatives, landrace-derived crosses, potential donor-based crosses and multi-parent-derived lines can therefore clarify the extent of variation generated through contrasting crossing strategies and identify promising material for further breeding. Such evaluation is particularly relevant where grain yield must be improved without compromising biomass production and adaptation to moisture-limited conditions.

Therefore, the present study aimed to: (i) estimate and compare the mean performance of crosses derived from (a) sorghum × maize derivatives, (b) landraces, (c) potential donor parents used as pollinators, and (d) multi-parent crosses derived from eight post-rainy-season sorghum parental lines; and (ii) compare and assess the genetic potential of multi-parent-derived crosses with single and other cross combinations under a rainfed post-rainy sorghum production environment.

MATERIALS AND METHODS:

Experimental material

The experimental material comprised 74 cross-derived entries representing diverse genetic backgrounds developed for post-rainy season sorghum improvement. Of these, 48 were multi-parent-derived genotypes developed from crosses involving eight post-rainy season sorghum parental lines (Table 1-a), while the remaining entries comprised 15 crosses in the M35-1 background, five in the CSV 26R background, two in the CSV 29R background, three in the Solapur Dagadi background, and one in the Phule Revati background (Table 1-a). The eight parental lines used for developing the multi-parent material were selected based on their diverse and complementary characteristics for important agronomic and adaptive traits, including early maturity, broad adaptation, yield potential, drought tolerance, grain quality, and resistance to insect pests and diseases. The experimental material represented diverse parental sources, including elite breeding lines, landraces, donor genotypes and sorghum–maize-derived backgrounds. Seeds of all 74 entries were obtained from the Centre on Rabi Sorghum, ICAR–Indian Institute of Millets Research (ICAR–IIMR), Regional Station, Shelgi, Solapur, Maharashtra, India, and were evaluated under rainfed post-rainy season conditions for yield and associated agronomic traits.

Table1- a: List of cross-derived genotypes evaluated in the study

Sr. No.	Genotype	Genetic background/category
1	CSV 26R × RS 1988	CSV 26R background
2	CSV 26R × SM2	CSV 26R background
3	CSV 26R × SM4	CSV 26R background
4	CSV 26R × SM6	CSV 26R background
5	CSV 26R × SM8	CSV 26R background

6	CSV 29R × IS 9742	CSV 29R background
7	CSV 29R × IS 15167	CSV 29R background
8	M35-1 × EP 98	M35-1 background
9	M35-1 × IS 15167	M35-1 background
10	M35-1 × IS 4506	M35-1 background
11	M35-1 × IS 9742	M35-1 background
12	M35-1 × PEC-15	M35-1 background
13	M35-1 × RSV 1988	M35-1 background
14	M35-1 × SM-1	M35-1 background
15	M35-1 × SM-2	M35-1 background
16	M35-1 × SM-3	M35-1 background
17	M35-1 × SM-4	M35-1 background
18	M35-1 × SM-5	M35-1 background
19	M35-1 × SM-6	M35-1 background
20	M35-1 × SM-8	M35-1 background
21	M35-1 × VJV-111	M35-1 background
22	M35-1 × VJV-114	M35-1 background
23	MC-1	Multi-parent-derived
24	MC-10	Multi-parent-derived
25	MC-11	Multi-parent-derived
26	MC-12	Multi-parent-derived
27	MC-14	Multi-parent-derived
28	MC-15	Multi-parent-derived
29	MC-16	Multi-parent-derived
30	MC-17	Multi-parent-derived
31	MC-18	Multi-parent-derived
32	MC-19	Multi-parent-derived
33	MC-2	Multi-parent-derived
34	MC-20	Multi-parent-derived
35	MC-21	Multi-parent-derived
36	MC-22	Multi-parent-derived
37	MC-23	Multi-parent-derived
38	MC-24	Multi-parent-derived
39	MC-25	Multi-parent-derived
40	MC-26	Multi-parent-derived
41	MC-27	Multi-parent-derived
42	MC-28	Multi-parent-derived
43	MC-29	Multi-parent-derived
44	MC-3	Multi-parent-derived
45	MC-30	Multi-parent-derived
46	MC-31	Multi-parent-derived
47	MC-32	Multi-parent-derived
48	MC-33	Multi-parent-derived
49	MC-34	Multi-parent-derived
50	MC-35	Multi-parent-derived
51	MC-36	Multi-parent-derived
52	MC-37	Multi-parent-derived
53	MC-38	Multi-parent-derived

54	MC-39	Multi-parent-derived
55	MC-4	Multi-parent-derived
56	MC-40	Multi-parent-derived
57	MC-41	Multi-parent-derived
58	MC-42	Multi-parent-derived
59	MC-43	Multi-parent-derived
60	MC-44	Multi-parent-derived
61	MC-45	Multi-parent-derived
62	MC-46	Multi-parent-derived
63	MC-47	Multi-parent-derived
64	MC-48	Multi-parent-derived
65	MC-49	Multi-parent-derived
66	MC-5	Multi-parent-derived
67	MC-51	Multi-parent-derived
68	MC-7	Multi-parent-derived
69	MC-8	Multi-parent-derived
70	MC-9	Multi-parent-derived
71	Phule Revati × IS 9742	Phule Revati background
72	Solapur Dagadi × IS 15167	Solapur Dagadi background
73	Solapur Dagadi × IS 4506	Solapur Dagadi background
74	Solapur Dagadi × IS 9742	Solapur Dagadi background

Table 1- b: List of Multi-parent crosses with their Pedigree

Identity	**Pedigree**
MC-1	[(Sel. 3 x CRS 4) x (Solapur Dagadi x Phule Revati)] x [(Sel.3 x Solapur Dagadi) x (Sel.3 x CRS 4)]
MC-10	[(CSV 14R x PKV Kranti) x (CSV 14R x Phule Revati)] x [(CSV26 x DSV 4) x (CSV 14R x Phule Revati)]
MC-11	[(CSV 14R x PKV Kranti) x (CSV 14R x Phule Revati)] x [(Phule Anuradha x Parbhani Moti) x (CSV 216R x CRS 4)]
MC-12	[(CRS 4 x DSV 4) x (CRS 4 x Solapur Dagadi)] x [(CSV 216R x CRS 4) x (M 35-1 x CSV 29R)]
MC-14	[(CRS 4 x DSV 4) x (M 35-1 x CSV 29R)] x [(CSV 26 x DSV 4) x (CSV 14R x Phule Revati)]
MC-15	[(CRS 4 x DSV 4) x (M 35-1 x CSV 29R)] x [(Sel.3 x Solapur Dagadi) x (Sel.3 x CRS 4)]
MC-16	[(M 35 -1 x CSV 29R) x (CSV 216R x CRS 4)] x [(CRS 14R x Solapur Dagadi) x (CRS 4 x Phule Revati)]
MC-17	[(M 35 -1 x CSV 29R) x (CSV 216R x CRS 4)] x [(Parbhani Moti x CRS 20) x (M 35-1 x CSV 29R)]
MC-18	[(CRS 14R x Solapur Dagadi) x (CRS 4 x Phule Revati)] x [(CSV 14R x PKV Kranti) x (CSV 14R x Phule Revati)]
MC-19	[(CRS 14R x Solapur Dagadi) x (CRS 4 x Phule Revati)] x [(M 35-1 x CSV 22) x (Phule Chitra x CSV 22)]
MC-2	[(Sel.3 x CRS 4) x (Solapur Dagadi x Phule Revati)] x [(Sel.3 x Parbhani Moti) x (Sel.3 x Solapur Dagadi)]
MC-20	[(CSV 26 x DSV 4) x (CSV 14R x Phule Revati)] x [(PKV Kranti x Solapur Dagadi) x (Phule Suchitra x CSV 14R)]
MC-21	[(CSV 26 x DSV 4) x (CSV 14R x Phule revati)] x [(Parbhani Moti x CRS 20) x (M 35-1 x CSV 29R)]
MC-22	[(DSV 5 x Sel 3) x (Parbhani Moti x CRS 20)] x [(Sel. 3 x CRS 4) x (Solapur Dagadi x Phule Revati)]
MC-23	[(DSV 5 x Sel 3) x (Parbhani Moti x CRS 20)] x [(CSV 29R x PKV Kranti) x (Parbhani Moti x DSV 5)]
MC-	[(CRS 4 x Phule Revati) x (PKV Kranti x Phule Revati)] x [(CSV 26 x DSV 4) x (CSV 14R x Phule

24	Revati)]
MC-25	[(CRS 4 x Phule Revati) x (PKV Kranti x Phule Revati)] x [(DSV 5 x Sel 3) x (Parbhani Moti x CRS 20)]
MC-26	[(PKV Kranti x Solapur Dagadi) x (Phule Suchitra x CSV 14R)] x [(M 35-1 x CSV 29R) x (CSV 216R x CRS 4)]
MC-27	[(PKV Kranti x Solapur Dagadi) x (Phule Suchitra x CSV 14R)] x [(Parbhani Moti x CRS 20) x (M 35-1 x CSV 29R)]
MC-28	[(CSV 14R x DSV 4) x (CSV 26 x PKV Kranti)] x [(CSV 26 x Phule Suchitra) x (DSV 5 x Phule Revati)]
MC-29	[(CSV 14R x DSV 4) x (CSV 26 x PKV Kranti)] x [(CSV 29R x PKV Kranti) x (Parbhani Moti x DSV 5)]
MC-3	[(CSV 26 x CRS 4) (CRS 4 x Sel.3)] x [(Sel.3 x Solapur Dagadi) x (Sel.3 x CRS 4)]
MC-30	[(Parbhani Moti x CRS 20) x (M 35-1 x CSV 29R)] x [(CSV 14R x PKV Kranti) x (CSV 14R x Phule Revati)]
MC-31	[(Parbhani Moti x CRS 20) x (M 35-1 x CSV 29R)] x [(DSV 5 x Sel.3) x (Parbhani Moti x CRS 20)]
MC-32	[(Parbhani Moti x CRS 20) x (M 35-1 x CSV 29R)] x [(PKV Kranti x Solapur Dagadi) x (Phule Suchitra x CSV 14R)]
MC-33	[(Parbhani Moti x CRS 20) x (M 35-1 x CSV 29R)] x [(M 35-1 x CSV 22) x (Phule Chitra x CSV 22)]
MC-34	[(CSV 26 x Phule Suchitra) x (DSV 5 x Phule Revati)] x [(CRS 4 x Phule Revati) x (PKV Kranti x Phule Revati)]
MC-35	[(CSV 26 x Phule Suchitra) x (DSV 5 x Phule Revati)] x [(Parbhani Moti x CRS 20) x (M 35-1 x CSV 29R)
MC-36	[(M 35-1 x CSV 22) x (Phule Chitra x CSV 22)] x [(DSV 5 x Sel.3) x (Parbhani Moti x CRS 20)]
MC-37	[(M 35-1 x CSV 22) x (Phule Chitra x CSV 22)] x [(Phule Revati x Parbhani Moti) x (DSV 5 x Phule Suchitra)]
MC-38	[(Phule Revati x Parbhani Moti) x (DSV 5 x Phule Suchitra)] x [(CSV 26 x Phule Suchitra) x (DSV 5 x Phule Revati)]
MC-39	[(Phule Revati x Parbhani Moti) x (DSV 5 x Phule Suchitra)] x [(Parbhani Moti x CRS 20) x (M 35-1 x CSV 29R)
MC-4	[(CSV 26 x CRS 4) x (CRS 4 x Sel.3)] x [(CSV 216R x CRS 4) x (M 35-1 x CSV 29R)]
MC-40	[(CSV 29R x PKV Kranti) x (Parbhani Moti x DSV 5)] x [(CRS 4 x Phule Revati) x (PKV Kranti x Phule Revati)]
MC-41	[(CSV 29R x PKV Kranti) x (Parbhani Moti x DSV 5)] x [(CSV 26 x Phule Suchitra) x (DSV 5 x Phule Revati)]
MC-42	[(DSV 5 x Phule Revati)] x (CSV 216R x CSV 29R)] x [(CSV 14R x DSV 4) x (CSV 26 x PKV Kranti)]
MC-43	[(DSV 5 x Phule Revati)] x (CSV 216R x CSV 29R)] x [(CSV 29R x PKV Kranti) x (Parbhani Moti x DSV 5)]
MC-44	[(CSV 14R x Phule Revati) x (CSV 26 x Phule Revati)] x [(Phule Revati x Parbhani Moti) x (DSV 5 x Phule Suchitra)]
MC-45	[(CSV 14R x Phule Revati) x (CSV 26 x Phule Revati)] x [(Phule Chitra x CSV 22) x (M 35-1 x CSV 22)
MC-46	[(Phule Chitra x CSV 22) x (M 35-1 x CSV 22)] x [(CSV 14R x Phule Revati) x (CSV 26 x Phule Revati)]
MC-47	[(Phule Anuradha x Parbhani Moti) x (CSV 216R x CRS 4)] x [(PKV Kranti x Solapur Dagadi) x (Phule Suchitra x CSV 14R)]
MC-48	[(Phule Anuradha x Parbhani Moti) x (CSV 216R x CRS 4)] x [(CSV 26 x Phule Suchitra) x (DSV 5 x Phule Revati)]
MC-49	[(Phule Anuradha x Parbhani Moti) x (CSV 216R x CRS 4)] x [(M 35-1 x CSV 22) x (Phule Chitra x x CSv 22)]
MC-5	[(Sel.3 x Solapur Dagadi) x (Sel.3 x CRS 4)] x [(Sel. 3 x CRS 4) x (Solapur Dagadi x Phule Revati)]
MC-51	[(CRS 4 x Sel. 3) x (DSV 5 x Sel.3)] x [(DSV 5 x Phule Kranti) x (CSV 216R x CSv 29R)]
MC-7	[(Sel.3 x Parbhani Moti) x (Sel.3 x Solapur Dagadi)] x [(Sel. 3 x CRS 4) x (Solapur Dagadi x Phule Revati)]
MC-8	[(Sel.3 x Parbhani Moti) x (Sel.3 x Solapur Dagadi)] x [(CSV 26 x CRS 4) x (CRS 4 x Sel.3)]
MC-9	[(CSV 14R x PKV Kranti) x (CSV 14R x Phule Revati)] x [(CSV 216R x CRS4) x (M35-1 x

	CSV29R)]

Development of multi-parent crosses

The 48 multi-parent crosses evaluated in the present study originated from a multi-parent crossing programme involving 19 elite post-rainy season sorghum founder lines selected for genetic diversity, yield potential, adaptation and tolerance to major biotic and abiotic stresses. Multi-parent populations were developed through a sequential intercrossing strategy involving pairwise (2-way), 4-way and 8-way crosses, followed by selfing and pedigree-based selection over successive generations. Advanced generation progenies were developed through intensive phenotypic selection to capture favourable recombination events and transgressive segregants. The resulting stabilized derivatives constituted a major component of the experimental material evaluated in the present investigation (Patroti et al., 2025).

Field evaluation:

The experimental material was evaluated during the post-rainy season of 2020–2021 at the rainfed research farm of the ICAR–Indian Institute of Millets Research (ICAR–IIMR), Regional Station, Shelgi, Solapur, Maharashtra, India (17°40′ N, 75°54′ E; 473 m above sea level). The experimental field was characterized by deep soil. Each entry was grown in a single 3 m row, with a spacing of 45 cm between rows and 15 cm between plants. Recommended agronomic and crop protection practices were followed throughout the crop season to ensure uniform crop establishment and optimum phenotypic expression. Fertilizers were applied at the recommended dose of 60:30:0 kg using urea and NPK fertilizers. Supplementary irrigation was provided when required, particularly during critical crop growth stages, to prevent excessive moisture stress.

Trait recording:

Observations were recorded following the Standard Key Descriptor List for Characterization of Sorghum (IIMR and ICRISAT, 1984). Five randomly selected plants from each entry in each replication were used for recording plant-level observations. Data were recorded for eight quantitative traits, comprising days to 50% flowering (DF), plant height (PH), panicle exertion (PE), peduncle length (PedL), panicle length (PL), grain yield per plant (GYPP), stover yield per plant (SYPP), and 1000-seed weight (1000 SW). Days to 50% flowering was recorded when approximately 50% of the plants in an entry had reached flowering. Plant height was measured from the ground level to the tip of the panicle at maturity (cm), while panicle exertion was measured from the flag leaf to the base of the panicle (cm). Panicle length was measured from the lower panicle branch to the tip of the panicle (cm), Grain yield per plant was determined from the grain obtained after threshing the sampled plants, while stover yield per plant was recorded as the dry weight of the corresponding plant biomass (g). 1000-seed weight was determined by weighing 1000 grains (g).

Data analysis:

Descriptive statistics, including mean, standard error, standard deviation, range and coefficient of variation (CV), were calculated for all nine quantitative traits. Analysis of variance (ANOVA) was performed using an RCBD model to assess differences among the 74 cross-derived entries, and phenotypic correlations among traits were estimated. All analyses were performed using R software with the agricolae package (version 1.3-2).

3. RESULT AND DISCUSSION:

3.1 Analysis of variance and experimental precision

Analysis of variance revealed highly significant differences ($P < 0.001$) among the 74 cross-derived entries for all eight traits evaluated, including flowering time, plant architecture, panicle traits, grain yield, stover yield and seed weight (Table 2). The coefficients of variation ranged from 3.63% for days to flowering to 19.91% for stover yield per plant, indicating adequate experimental precision.

Table 2. Analysis of Variance (ANOVA) for different Rabi Adaptive traits in a set of different hybrid combinations

	DF (50%) (days)	PH (cm)	PE (cm)	PedL (cm)	PL (cm)	GYPP (g)	SYPP (g)	1000 SW (g)
Number of Replication	2	2	2	2	2	2	2	2
Number of Treatment	74	74	74	74	74	74	74	74
Treatment Mean Sum of Square	32.7702 ***	843.7668 ***	33.5192 ***	52.5719 ***	9.4484 ***	246.4988 ***	404.1747 ***	21.2939 ***
Replication Mean Sum of Square	0.0068 ns	19787.4844 ***	106.7601 ***	544.3974 ***	18.9451 ***	5573.3616 ***	483.3012 *	8.4793 ns
Error	6.23	356.78	8.43	17.60	1.57	86.26	105.40	7.87

Mean Sum of Square								
Trait Mean	68.76	231.83	14.78	36.44	16.79	47.49	51.56	31.30
Minimum	56	168	5	24.6	10.6	20	22.3	18.6
Maximum	85	295	31.8	56	23.2	97	119	42
CV	3.63	8.15	19.65	11.51	7.46	19.56	19.91	8.96
Std Error(m)	1.76	13.36	2.05	2.97	0.89	6.57	7.26	1.98
Std Error(d)	2.50	18.89	2.90	4.19	1.25	9.29	10.27	2.81

ns, non-significant; *, significant at P < 0.05; ***, significant at P < 0.001, DF, days to 50% flowering; PH, plant height; PE, panicle exertion; PedL, peduncle length; PL, panicle length; GYPP, grain yield per plant; SYPP, stover yield per plant; 1000 SW, 1000-seed weight; CV, coefficient of variation; SE(m), standard error of mean; SE(d), standard error of difference

3.2: Variation in mean performance of cross-derived entries

The 74 cross-derived entries exhibited substantial variation for all eight quantitative traits evaluated (Table 3). Days to 50% flowering ranged from 56.5 to 84.5 days, while plant height varied from 171.5 to 294.0 cm. Panicle exertion ranged from 5.60 to 31.45 cm, peduncle length from 27.15 to 55.50 cm, and panicle length from 11.10 to 22.72 cm. Considerable variation was also observed for yield-associated traits, with grain yield per plant, stover yield per plant and 1000-seed weight ranging from 25.00–96.55 g, 29.00–115.00 g and 19.80–40.60 g, respectively. The corresponding overall means were 68.76 days, 231.83 cm, 14.78 cm, 36.44 cm, 16.79 cm, 47.49 g, 51.56 g and 31.30 g for days to 50% flowering, plant height, panicle exertion, peduncle length, panicle length, grain yield per plant, stover yield per plant and 1000-seed weight, respectively.

Among the evaluated entries, MC-28 exhibited the most favourable overall performance, recording the highest mean values for plant height (294.0 cm), grain yield per plant (96.55 g), stover yield per plant (115.0 g) and 1000-seed weight (40.60 g). Other notable entries for grain yield per plant were MC-2 (68.25 g), MC-45 (72.65 g), MC-14 (64.80 g), MC-10 (60.70 g), MC-17 (56.60 g), M35-1 × SM-5 (58.25 g), MC-11 (58.10 g), MC-19 (54.60 g) and MC-29 (54.60 g). High stover yield per plant was also recorded for M35-1 × SM-1 (77.05 g), M35-1 × EP 98 (75.54 g), MC-14 (73.30 g), MC-24 (72.79 g), M35-1 × SM-5 (71.00 g), MC-4 (69.81 g) and MC-45 (66.96 g). For maturity and plant architecture, Solapur Dagadi × IS 9742 showed the earliest flowering (56.5 days), whereas MC-3 was the latest flowering entry (84.5 days); Phule Revati × IS 9742 recorded the highest panicle exertion (31.45 cm), while MC-9 showed the longest peduncle (55.50 cm).

Overall, the wide range of mean performance observed across the evaluated entries demonstrates the diverse phenotypic expression generated by the different cross backgrounds, particularly for yield and yield-associated traits.

Table 3. Mean performance and descriptive statistics of 74 cross-derived entries for eight quantitative traits

	DF (days)	PH (cm)	PE (cm)	PedL (cm)	PL (cm)	GYPP (g)	SYPP (g)	1000 SW (g)
CSV26R X RS 1988	73.00	237.00	17.40	43.85	18.14	39.20	44.17	27.59
CSV26R X SM2	66.00	225.50	13.30	35.20	20.73	41.60	62.56	33.48
CSV26R X SM4	65.50	202.50	10.30	30.80	16.27	34.40	36.90	29.78
CSV26R X SM6	67.50	264.00	16.20	37.35	18.78	35.45	85.50	34.88
CSV26R X SM8	69.00	208.90	18.40	36.90	16.33	32.15	48.66	29.88
CSV29R X IS 9742	64.00	261.00	26.20	49.20	22.72	56.75	50.08	32.37
CSV29R X IS15167	72.00	246.00	16.90	47.40	19.27	54.58	62.62	35.27
M35-1 X EP 98	72.00	219.50	11.00	33.20	16.26	43.80	75.54	28.32
M35-1 X IS 15167	70.00	226.00	17.30	43.60	18.64	36.20	47.05	27.90
M35-1 X IS 4506	72.00	206.50	15.40	34.40	14.49	38.33	43.06	31.87
M35-1 X IS 9742	60.00	228.00	17.50	38.20	16.13	39.60	40.52	32.65
M35-1 X PEC-15	73.50	216.00	17.70	38.80	13.78	34.80	53.20	29.96
M35-1 X RSV 1988	72.00	226.00	12.10	36.30	15.55	36.80	34.93	30.78
M35-1 X SM-1	66.00	248.50	15.20	41.70	20.17	38.38	77.05	32.83
M35-1 X SM-2	68.50	213.50	8.85	30.70	17.89	51.99	34.71	34.20

M35-1 X SM-3	66.50	240.00	17.10	43.20	16.52	35.50	51.68	31.97
M35-1 X SM-4	65.50	207.00	12.30	37.20	15.33	31.60	37.01	28.60
M35-1 X SM-5	64.00	241.00	11.55	36.50	20.88	58.25	71.00	39.37
M35-1 X SM-6	64.50	197.50	17.40	41.00	17.40	44.40	35.42	30.94
M35-1 X SM-8	64.00	191.00	16.20	41.20	15.31	36.40	42.60	36.82
M35-1 X VJV-111	71.00	235.00	11.50	36.70	16.53	45.30	55.41	27.26
M35-1 X VJV 114	70.50	255.00	10.65	27.15	15.91	52.90	59.20	32.25
MC-1	66.50	208.00	19.00	32.30	15.15	67.38	35.25	33.70
MC-10	69.50	244.00	14.80	38.50	19.24	60.70	52.87	32.83
MC-11	66.00	258.50	14.30	35.40	19.54	58.10	53.83	32.87
MC-12	67.50	246.00	5.60	30.00	15.55	35.00	52.25	20.50
MC-14	69.50	257.50	12.70	37.20	19.02	64.80	73.30	29.86
MC-15	66.00	238.50	13.40	32.70	15.83	47.80	54.30	33.21
MC-16	67.00	234.00	16.00	38.30	16.62	53.65	63.55	29.40
MC-17	73.50	222.00	14.15	36.75	16.75	56.60	56.61	34.23
MC-18	68.50	247.50	12.00	34.90	14.91	41.80	45.22	29.95
MC-19	69.50	251.00	10.90	34.40	17.78	54.60	50.71	32.47
MC-2	71.00	203.50	16.90	31.20	14.54	68.25	42.17	25.97
MC-20	65.00	238.50	18.60	41.00	19.94	52.95	41.67	31.13
MC-21	66.00	247.50	12.10	37.10	19.23	49.50	49.20	31.10
MC-22	72.00	249.00	15.20	35.90	16.04	47.70	52.84	32.31
MC-23	72.00	225.50	14.10	33.90	15.16	38.70	61.26	30.22
MC-24	72.00	260.50	13.00	36.10	17.59	47.80	72.79	31.62
MC-25	68.50	240.00	9.60	30.50	16.16	40.80	54.69	32.91
MC-26	72.00	226.50	11.90	33.00	14.16	40.10	33.92	27.39
MC-27	69.50	226.50	13.60	33.30	15.48	54.00	41.76	31.54
MC-28	71.00	294.00	15.35	35.45	18.60	96.55	115.00	40.60
MC-29	68.00	269.00	16.25	38.00	18.52	54.60	60.80	34.86
MC-3	84.50	171.50	14.25	34.10	11.50	25.00	29.00	19.80
MC-30	72.00	236.00	8.70	30.50	15.32	50.00	55.79	32.79
MC-31	74.00	211.00	12.10	33.20	14.92	40.60	41.18	32.16
MC-32	71.00	222.50	14.50	33.45	16.09	53.45	66.05	35.56
MC-33	72.00	234.00	17.40	36.30	15.43	45.80	54.77	30.28
MC-34	72.00	230.50	10.30	33.30	14.76	28.80	45.16	30.67
MC-35	69.50	227.00	12.30	31.90	15.97	49.50	46.06	32.28
MC-36	65.00	212.50	10.20	31.30	16.30	44.60	60.15	32.58
MC-37	67.50	230.50	14.70	38.70	16.89	44.30	52.80	26.51
MC-38	67.50	223.50	12.70	33.00	16.93	45.90	49.69	31.10
MC-39	69.50	226.50	14.50	34.70	16.88	48.50	39.20	28.98
MC-4	64.50	247.50	13.40	39.40	22.01	56.30	69.81	31.30
MC-40	72.00	228.50	13.80	33.70	15.91	37.20	42.28	28.80
MC-41	69.50	231.50	11.90	33.80	18.06	57.40	55.52	29.04
MC-42	74.00	217.00	13.30	31.30	14.97	44.40	63.85	30.27
MC-43	72.00	259.00	15.30	37.60	16.85	45.10	47.23	27.89
MC-44	71.50	253.50	16.70	42.70	17.92	49.15	51.92	29.84
MC-45	73.50	254.00	19.25	36.05	18.72	72.65	66.96	30.58
MC-46	72.50	253.00	13.80	35.60	16.88	43.00	57.88	28.80
MC-47	66.00	214.00	13.50	33.50	15.69	48.70	41.00	30.08

MC-48	65.50	244.00	16.90	45.25	18.93	41.50	35.58	30.57
MC-49	72.00	227.00	11.90	34.00	14.92	38.60	39.53	29.28
MC-5	68.00	209.75	15.15	33.28	14.13	50.98	46.67	31.59
MC-51	66.50	230.00	13.80	36.40	15.50	40.60	37.23	32.47
MC-7	65.00	206.50	13.30	31.50	14.39	55.30	33.24	32.44
MC-8	63.00	208.00	12.70	30.40	16.44	48.30	36.27	31.97
MC-9	73.50	223.25	28.50	55.50	19.25	60.00	32.50	34.35
Phule Revati x IS 9742	63.50	263.50	31.45	50.80	20.36	51.50	60.54	33.43
Solapur Dagadi x IS 15167	64.00	223.25	22.40	43.00	15.80	51.60	51.38	34.05
Solapur Dagadi x IS 4506	63.50	227.00	18.20	32.50	11.10	51.35	47.32	35.75
Solapur Dagadi x IS 9742	56.50	227.00	16.95	33.05	14.94	44.35	45.96	33.12
Trait Mean	68.76	231.83	14.78	36.44	16.79	47.49	51.56	31.30
SE	1.76	13.36	2.05	2.97	0.89	6.57	7.26	1.98
Min	56.00	168.00	5.00	24.60	10.60	20.00	22.30	18.60
Max	85.00	295.00	31.80	56.00	23.20	97.00	119.00	42.00
CV	3.63	8.15	19.65	11.51	7.46	19.56	19.91	8.96

DF, days to 50% flowering; PH, plant height; PE, panicle exertion; Ped L, peduncle length; PL, panicle length; GYPP, grain yield per plant; SYPP, stover yield per plant; 1000 SW, 1000-seed weight

3.3 Comparative performance of cross-derived categories

Category-wise comparison revealed distinct patterns of mean performance for the major productivity traits among the evaluated genetic backgrounds (Table 4; Fig. 1).

Table 4. Comparative mean performance of cross-derived categories for eight quantitative traits.

Cross category	n	DF (days)	PH (cm)	PE (cm)	PedL (cm)	PL (cm)	GYPP (g)	SYPP (g)	1000 SW (g)
CSV 26R background	5	68.20	227.58	15.12	36.82	18.05	36.56	55.55	31.12
CSV 29R background	2	68.00	253.50	21.55	48.30	20.99	55.66	56.35	33.82
M35-1 background	15	68.00	223.37	14.12	37.32	16.72	41.62	50.56	31.71
Multi-parent-derived	48	69.67	233.74	14.05	35.34	16.61	49.94	51.28	30.85
Phule Revati background	1	63.50	263.50	31.45	50.80	20.36	51.50	60.54	33.43
Solapur Dagadi background	3	61.33	225.75	19.18	36.18	13.95	49.10	48.22	34.31

The multi-parent-derived entries (n = 48) recorded a mean grain yield of 49.94 g plant^{-1}, compared with 41.62 g plant^{-1} for the M35-1 background and 36.56 g plant^{-1} for the CSV 26R background. The CSV 29R background (n = 2) recorded the highest category mean for grain yield (55.66 g plant^{-1}), followed by the Phule Revati background (51.50 g plant^{-1}) and multi-parent-derived entries (49.94 g plant^{-1}). For stover yield, the Phule Revati background showed the highest mean (60.54 g plant^{-1}), followed by CSV 29R (56.35 g plant^{-1}) and CSV 26R (55.55 g plant^{-1}), whereas the multi-parent-derived material recorded 51.28 g plant^{-1}. For 1000-seed weight, the Solapur Dagadi background showed the highest mean (34.31 g), followed by CSV 29R (33.82 g) and the Phule Revati background (33.43 g). Given the unequal representation of genetic backgrounds, particularly the categories represented by one to three entries, these differences are interpreted descriptively rather than as evidence of statistical superiority among categories. Notably, the multi-parent-derived material combined a comparatively favourable mean grain yield with the largest representation (n = 48) in the evaluated population, supporting its potential as a broad source of selectable variation for post-rainy sorghum improvement.

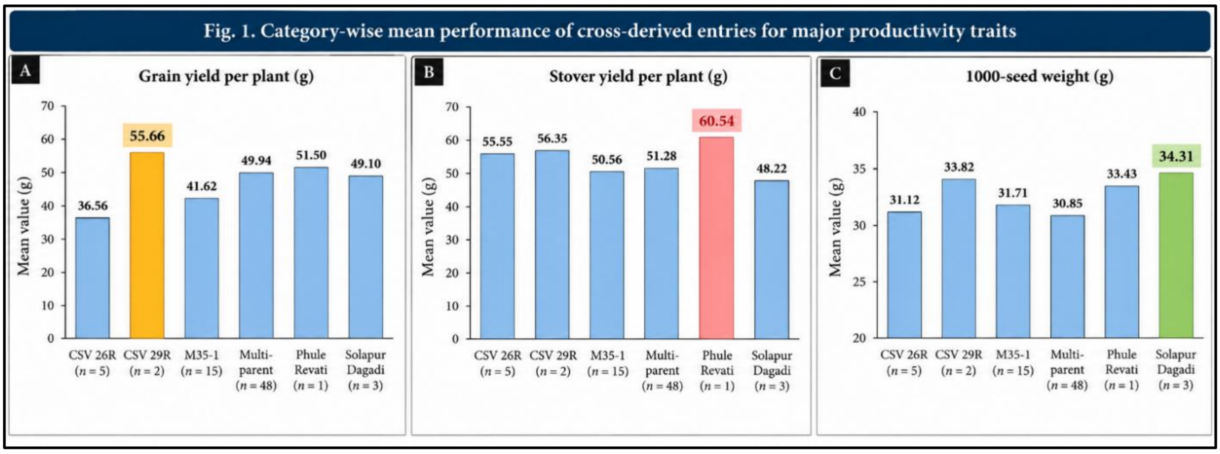


Fig.1: Category-wise mean performance of cross-derived entries for nine quantitative traits

3.4 Identification of promising cross-derived entries

Ranking of the 74 cross-derived entries identified promising material for grain yield per plant (GYPP), stover yield per plant (SYPP) and 1000-seed weight (1000 SW), as presented in Fig. 2a–c. MC-28 consistently ranked first for all three traits, recording 96.55 g GYPP, 115.00 g SYPP and 40.60 g 1000 SW. Notably, MC-28, M35-1 × SM-5, MC-14, MC-45, MC-32 and MC-9 occurred among the top-ranking entries for two or more traits, indicating comparatively consistent performance across yield-related attributes. Among these, MC-28 was distinctive in combining the highest observed grain yield, stover yield and 1000-seed weight.

Across the nine traits evaluated, MC-28 recorded the highest observed values for plant height (294.00 cm), panicle weight per plant (89.00 g), grain yield per plant (96.55 g), stover yield per plant (115.00 g) and 1000-seed weight (40.60 g). The highest observed values for the remaining traits were recorded by MC-3 for days to 50% flowering (84.50 days), Phule Revati × IS 9742 for panicle exertion (31.45 cm), MC-9 for peduncle length (55.50 cm), and CSV 29R × IS 9742 for panicle length (22.72 cm) (Table 3). Overall, MC-28 emerged as the most consistently high-performing cross-derived entry, while MC-45, MC-14, M35-1 × SM-5, MC-32 and MC-9 showed favourable performance across multiple yield-associated traits. These entries represent promising material for further evaluation under post-rainy season conditions.

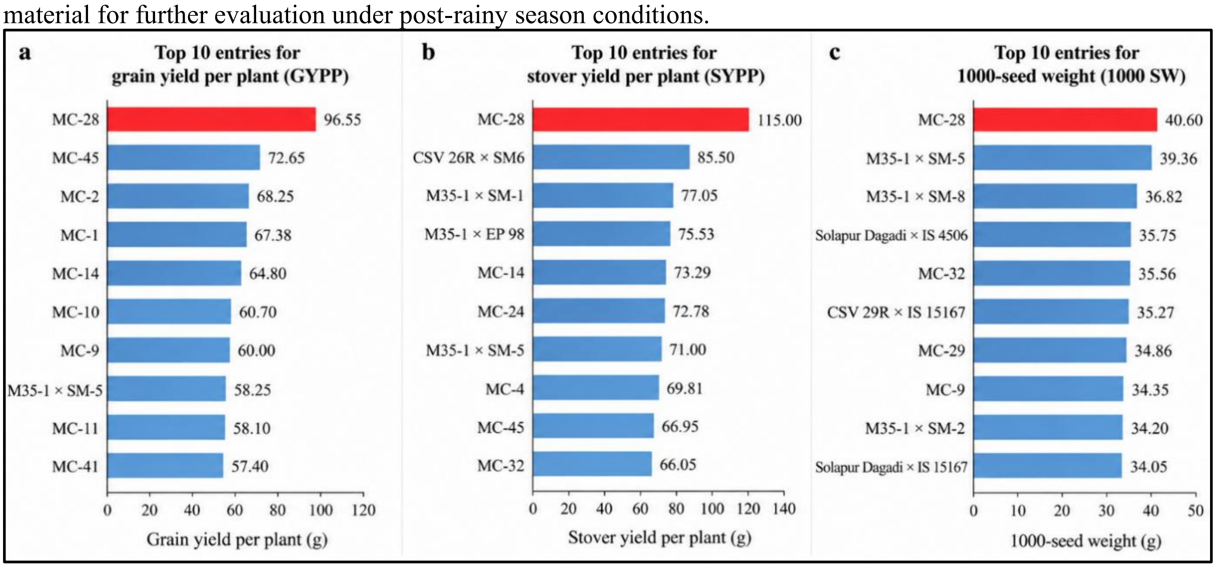


Fig. 2 a-c: Top 10 cross-derived entries for (a) grain yield per plant (b) Stover yield per plant (c) 1000-seed weight under post-rainy season conditions.

3.5 Genetic variability and selection parameters

The estimates of genotypic coefficient of variation (GCV), phenotypic coefficient of variation (PCV), broad-sense heritability (h^2), genetic advance (GA) and genetic advance as per cent of mean (GAM) indicated considerable variability among the evaluated cross-derived entries (Table 5). PCV exceeded GCV for all eight traits, indicating that environmental effects contributed to the observed phenotypic variation. GCV ranged from 5.30% for days to 50% flowering to 23.96% for panicle exertion, while PCV ranged from 6.42% for days to 50% flowering to 30.99% for panicle exertion. Among the yield-related traits, GYPP recorded a GCV of 18.85% and PCV of 27.16%, whereas SYPP showed relatively higher values of 23.71% and 30.96%, respectively.

Broad-sense heritability ranged from 40.56% for plant height to 71.50% for panicle length. High heritability was observed for days to 50% flowering (68.07%) and panicle length (71.50%), while the remaining traits exhibited moderate estimates. Genetic advance ranged from 3.46 for panicle length to 20.47 for plant height. The highest GAM values were recorded for panicle exertion (38.17%), stover yield per plant (37.40%) and grain yield per plant (26.94%), whereas lower GAM was observed for plant height (8.83%), days to 50% flowering (9.00%) and 1000-seed weight (11.57%).

The combination of comparatively high GCV, heritability and GAM for panicle exertion, stover yield per plant and grain yield per plant indicated substantial exploitable variability for these traits. In contrast, the relatively narrow GCV and lower GAM for days to 50% flowering and 1000-seed weight suggested comparatively limited selection response for these traits within the evaluated material. Overall, the estimates demonstrated the presence of exploitable genetic variability, particularly for yield and biomass-associated traits, providing a basis for selection within the cross-derived population.

Table 5: Estimates of genetic variability and selection parameters for eight quantitative traits

Trait	**GCV (%)**	**PCV (%)**	**Heritability (h^2, %)**	**Genetic advance (GA)**	**GAM (%)**
Days to 50% flowering	5.298	6.4215	68.0689	6.1917	9.0044
Plant height	6.7308	10.5682	40.5633	20.4727	8.8308
Panicle exertion	23.9619	30.9865	59.7999	5.6419	38.1715
Peduncle length	11.4774	16.2567	49.8451	6.082	16.6925
Panicle length	11.8201	13.9789	71.4985	3.4572	20.5891
Grain yield per plant	18.8486	27.1619	48.1544	12.7954	26.9441
Stover yield per plant	23.7072	30.9604	58.6338	19.2801	37.3957
1000-seed weight	8.2786	12.2017	46.0335	3.6213	11.5708

GCV, genotypic coefficient of variation; PCV, phenotypic coefficient of variation; h^2, broad-sense heritability; GA, genetic advance; GAM, genetic advance as per cent of mean.

3.6 Association among yield and yield-associated traits

Correlation analysis revealed distinct phenotypic, genotypic and environmental associations among the eight quantitative traits (Table 6). Grain yield per plant (GYPP) showed positive phenotypic correlations with plant height (P= 0.48), panicle length (P= 0.43), stover yield per plant (P = 0.43) and 1000-seed weight (P = 0.43). The corresponding genotypic correlations were 0.29, 0.25, 0.42 and 0.52, respectively, with the strongest genotypic association observed between GYPP and 1000-seed weight.

Stover yield per plant (SYPP) was positively correlated with plant height (P = 0.53; G = 0.87), panicle length (P = 0.40; G= 0.43), GYPP (P = 0.43; G = 0.42) and 1000-seed weight (P = 0.30; G = 0.50). Among the architectural traits, panicle exertion showed a strong positive association with peduncle length at both phenotypic (G = 0.77) and genotypic (G = 0.78) levels, while plant height was positively correlated with panicle length (P = 0.54; G = 0.67).

Days to 50% flowering generally showed weak associations with yield traits. Its correlation with GYPP was weakly negative at both phenotypic (P = −0.10) and genotypic (G = −0.04) levels, whereas its association with 1000-seed weight was negative and stronger at the genotypic level (G = −0.56; P = −0.30). Environmental correlations were comparatively strong for plant height–GYPP (E = 0.64) and panicle length–GYPP (E = 0.74).

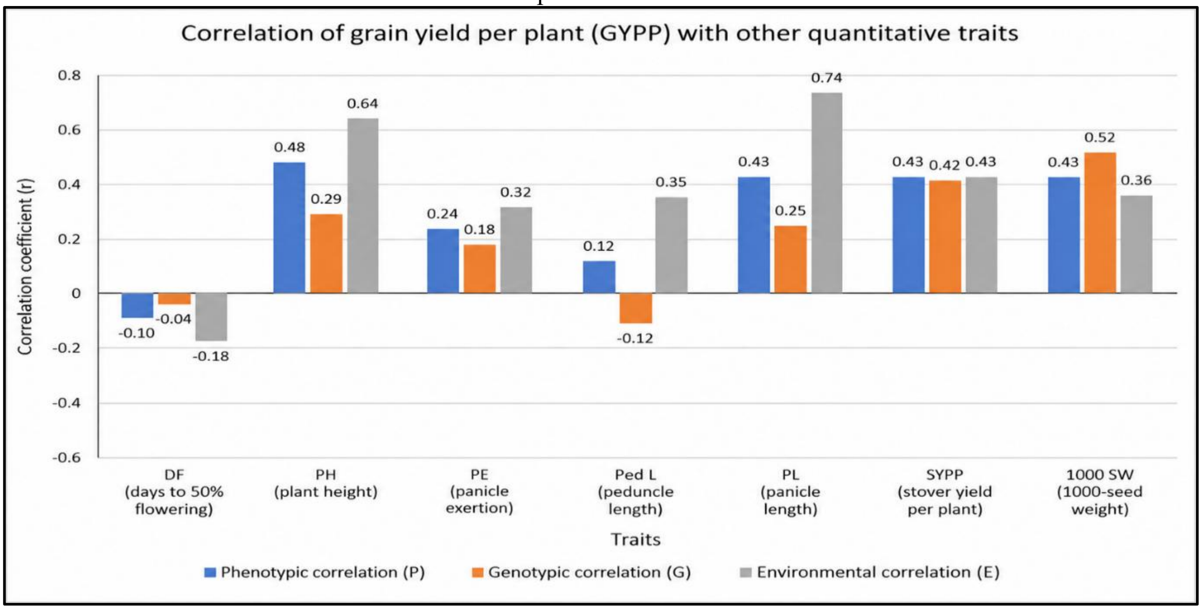
Overall, GYPP was positively associated with multiple yield-associated traits, with 1000-seed weight showing the strongest genotypic association (G = 0.52), followed by SYPP (G= 0.42). The consistency of these positive relationships across phenotypic and genotypic levels indicates their potential relevance in selection for grain productivity, although environmental contributions to several associations warrant validation across environments.

Table 6: Phenotypic, genotypic and environmental correlations among eight quantitative traits in 74 cross-derived entries.

Trait	**DF**	**PH**	**PE**	**Ped L**	**PL**	**GYPP**	**SYPP**	**1000 SW**
DF	P: 1.00; G: 1.00; E: 1.00	P: -0.05; G: -0.12; E: 0.03	P: -0.12; G: -0.21; E: 0.04	P: -0.09; G: -0.10; E: -0.07	P: -0.27; G: -0.26; E: -0.31	P: -0.10; G: -0.04; E: -0.18	P: 0.01; G: 0.08; E: -0.13	P: -0.30; G: -0.56; E: 0.02
PH		P: 1.00; G: 1.00; E: 1.00	P: 0.16; G: 0.02; E: 0.31	P: 0.33; G: 0.10; E: 0.51	P: 0.54; G: 0.67; E: 0.43	P: 0.48; G: 0.29; E: 0.64	P: 0.53; G: 0.87; E: 0.21	P: 0.29; G: 0.25; E: 0.32
PE			P: 1.00; G: 1.00; E: 1.00	P: 0.77; G: 0.78; E: 0.77	P: 0.27; G: 0.31; E: 0.22	P: 0.24; G: 0.18; E: 0.32	P: 0.00; G: -0.09; E: 0.13	P: 0.18; G: 0.31; E: 0.04
Ped L				P: 1.00; G: 1.00; E:	P: 0.51; G: 0.63; E:	P: 0.12; G: -0.12; E:	P: 0.04; G: 0.00;	P: 0.14; G: 0.15; E:

				1.00	0.35	0.35	E: 0.09	0.14
PL					P: 1.00; G: 1.00; E: 1.00	P: 0.43; G: 0.25; E: 0.74	P: 0.40; G: 0.43; E: 0.34	P: 0.28; G: 0.35; E: 0.21
GY PP						P: 1.00; G: 1.00; E: 1.00	P: 0.43; G: 0.42; E: 0.43	P: 0.43; G: 0.52; E: 0.36
SY PP							P: 1.00; G: 1.00; E: 1.00	P: 0.30; G: 0.50; E: 0.10
1000 SW								P: 1.00; G: 1.00; E: 1.00

DF, days to 50% flowering; PH, plant height; PE, panicle exertion; Ped L, peduncle length; PL, panicle length; GYPP, grain yield per plant; SYPP, stover yield per plant; 1000 SW, 1000-seed weight; P, phenotypic correlation coefficient; G, genotypic correlation coefficient; E, environmental correlation coefficient. Values are presented in



the order P; G; E**Figure 3: Phenotypic, genotypic and environmental correlations of grain yield per plant with other quantitative traits in 74 cross-derived entries. Values above the bars indicate correlation coefficients.**

Fig. 3 illustrates the correlations of GYPP with the seven remaining quantitative traits. GYPP showed positive associations with plant height, panicle exertion, panicle length, stover yield and 1000-seed weight, whereas days to 50% flowering showed a weak negative association. The strongest genotypic association of GYPP was observed with 1000-seed weight (r = 0.52), followed by stover yield per plant (r = 0.42). Overall, the positive associations of GYPP with 1000-seed weight and stover yield indicate their potential usefulness as selection criteria for improving grain productivity in post-rainy sorghum

3.7 Principal component analysis

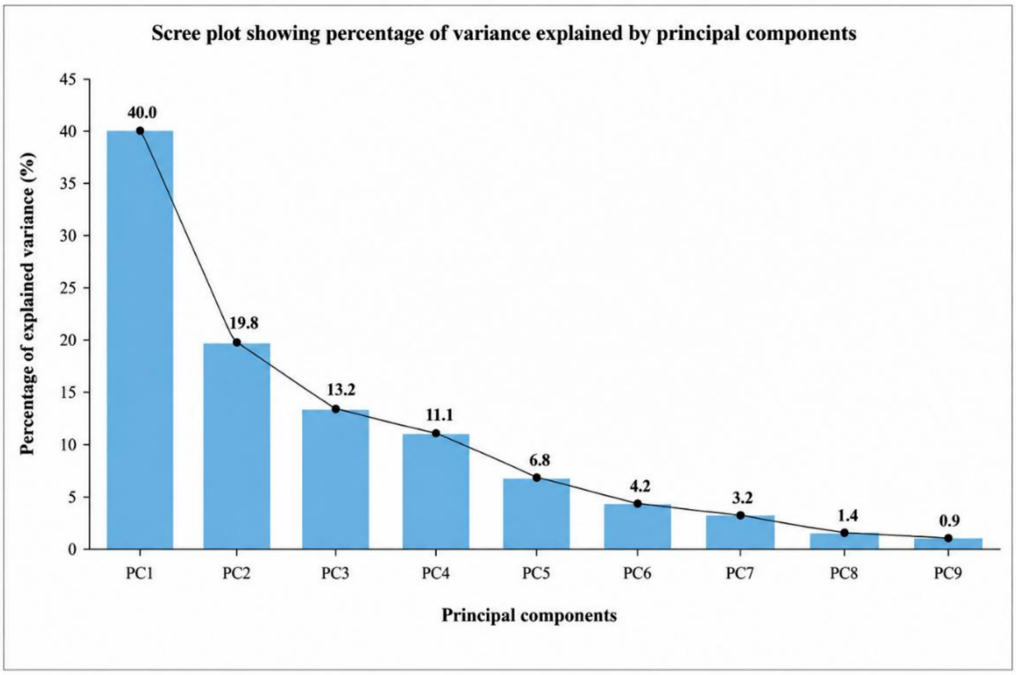


Fig 4. Percentage of total variance explained by successive principal components.

Principal component analysis revealed that the first four principal components accounted for 84.1% of the total variation among the 74 cross-derived entries (Fig. 4). PC1 contributed the highest proportion of variation (40.0%), followed by PC2 (19.8%), PC3 (13.2%) and PC4 (11.1%). The remaining components contributed relatively smaller proportions to the total variation. Thus, the first four principal components effectively summarized the major variation present in the evaluated cross-derived material.

4. DISCUSSION

The present study demonstrated substantial exploitable variation among the 74 cross-derived entries for yield and associated agronomic traits, providing a useful basis for selection in post-rainy sorghum. The highly significant variation observed across all eight evaluated traits, together with the broad ranges for grain yield, stover yield and 1000-seed weight, indicates considerable phenotypic diversity within the breeding material. Such diversity is particularly valuable in post-rainy sorghum, where productivity must be combined with adaptation to declining soil moisture and other production constraints (Patil et al., 2013).

The comparatively favourable performance of the multi-parent-derived material supports the value of broadening the recombination base beyond conventional biparental crossing. Multi-parent populations enable the combination of alleles from several founders and generate diverse recombination patterns, thereby increasing opportunities to recover favourable allele combinations for complex quantitative traits (Cavanagh et al., 2008; Rakshit et al., 2012). Their value for increasing genetic diversity and capturing useful variation for quantitative traits has also been demonstrated in sorghum (Kumar et al., 2023). In post-rainy sorghum, Patroti et al. (2017) demonstrated the potential of multi-genotype-derived material to generate superior recombinants and broaden the genetic base. Consistent with these observations, the multi-parent-derived entries in the present study exhibited a comparatively favourable mean grain yield relative to the M35-1 and CSV 26R background groups.

The estimates of genetic variability further supported the selection potential of the evaluated material. Grain yield per plant exhibited moderate genotypic variability, whereas stover yield and panicle exertion showed comparatively higher genotypic variation. The relatively high genetic advance as per cent of mean observed for several yield-associated traits further indicated scope for effective selection. However, broad-sense heritability represents the contribution of total genetic variance and should therefore not be interpreted as evidence of additive genetic control alone. Similar genetic variability and positive associations among productivity traits have been reported in rabi sorghum, supporting the usefulness of such variation for selection and population improvement (Swamy et al., 2018). The combination of genetic variability, heritability and genetic advance observed in the present material therefore provides opportunities for simultaneous improvement of grain productivity, biomass and associated agronomic attributes.

A major outcome of the study was the identification of MC-28 [(CSV 14R x DSV 4) x (CSV 26 x PKV Kranti)] x [(CSV 26 x Phule Suchitra) x (DSV 5 x Phule Revati)] as the most consistently promising cross-derived entry. As shown in the productivity comparisons, MC-28 recorded the highest observed values for plant height (294.00 cm), grain yield per plant (96.55 g), stover yield per plant (115.00 g) and 1000-seed weight (40.60 g) (Fig. 2). Its simultaneous expression of high grain productivity, biomass production and seed weight makes it particularly relevant as a breeding resource for post-rainy sorghum. This finding is consistent with the broader evidence from Patroti et al., (2025), where advanced multi-parent-derived post-rainy sorghum lines demonstrated superior grain and stover productivity together with favourable responses to drought and biotic stresses. Nevertheless, MC-28 should presently be regarded as a promising breeding entry rather than a superior cultivar, pending confirmation of its performance across environments and against appropriate checks.

The correlation analysis provided further insight into the relationships among yield and associated traits. Grain yield per plant showed positive phenotypic and genotypic associations with plant height, panicle length, stover yield and 1000-seed weight. Among these traits, 1000-seed weight exhibited the strongest genotypic association with grain yield (G = 0.52), followed by stover yield per plant (G = 0.42). The positive association between grain and stover yield also indicates the potential for simultaneous improvement of grain and biomass productivity, although the strength of this relationship should be evaluated across environments. Similar positive relationships among grain yield, stover yield and seed-weight-related traits have been reported in rabi sorghum (Swamy et al., 2018). Importantly, correlation coefficients indicate association rather than causation; therefore, the identified relationships should be considered as potential selection criteria rather than direct evidence of causal effects.

The present findings also complement conventional hybrid-oriented breeding strategies in sorghum. Combining ability and heterosis studies remain valuable for identifying superior parental combinations and hybrids for grain yield and associated traits in post-rainy sorghum (Veldandi et al., 2022; Vhanamane et al., 2026). Combining-ability-based heterotic grouping can further facilitate the identification of complementary parental groups for hybrid development (Verma et al., 2022). Multi-parent breeding can complement these approaches by generating a broader reservoir of recombined variation from which superior lines, breeding populations or parental resources can subsequently be identified. Thus, rather than replacing conventional hybrid breeding, multi-parent-derived populations can provide an expanded genetic foundation for subsequent selection and hybrid development.

The relevance of this strategy is particularly important for post-rainy sorghum because declining soil moisture during reproductive development can impose substantial limitations on crop productivity. Previous studies have demonstrated transgressive segregation and complex genetic control for post-flowering drought-related traits, emphasizing the importance of selection in advanced generations (Patil et al., 2013). The present experiment, however, primarily evaluated yield and morphological traits and did not directly quantify drought-response or physiological traits. Therefore, the superior performance of MC-28 should not be interpreted as evidence of drought tolerance. Instead, MC-28 and other promising entries require further evaluation under contrasting moisture regimes together with targeted physiological and biotic-stress screening. Such integrated evaluation is consistent with the multi-parent breeding framework of Patroti et al. (2025), in which advanced post-rainy sorghum derivatives were evaluated for productivity together with drought and biotic-stress responses.

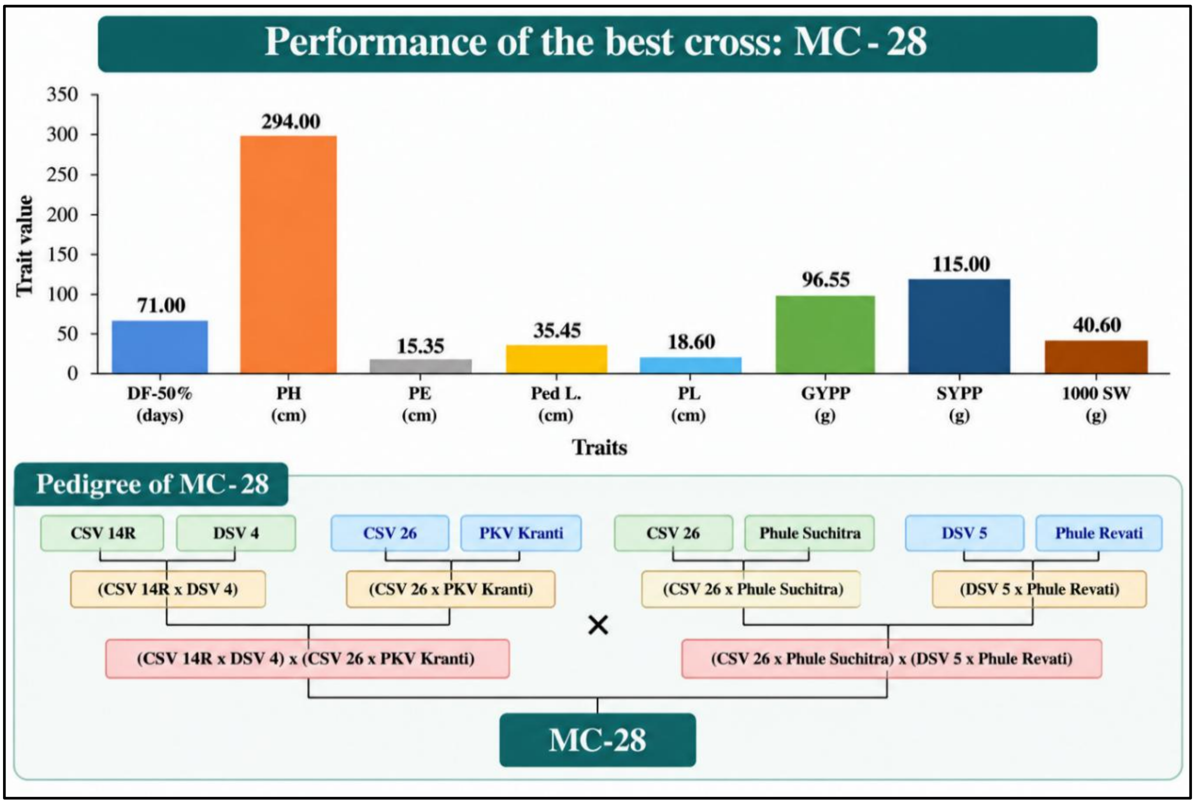


Figure 5. Phenotypic performance and pedigree of the outstanding multi-parent-derived entry MC-28.

Overall, the study demonstrates that multi-parent-derived material represents a valuable source of exploitable variation for post-rainy sorghum improvement, with MC-28 emerging as a particularly promising entry for grain yield, stover productivity and seed weight (Fig, 5). The positive genetic associations of grain yield with 1000-seed weight and stover yield provide useful selection information, while the broader diversity present within the multi-parent-derived population offers opportunities to recover favourable combinations of productivity-related traits. The findings support the integration of multi-parent breeding with conventional hybrid and heterotic-group-based approaches and provide a foundation for subsequent multi-environment testing, genotype × environment analysis and targeted stress-response evaluation. Such validation will be essential for determining the stability, adaptability and broader breeding value of MC-28 and other promising cross-derived entries.

5. CONCLUSION

The present study revealed substantial genetic and phenotypic variation among 74 cross-derived post-rainy sorghum entries, providing considerable scope for selection for grain yield and associated productivity traits. The multi-parent-derived material exhibited favourable performance for grain yield, panicle weight and related traits, demonstrating the potential of multi-parent recombination to generate diverse and superior segregants. MC-28 was identified as the most promising entry, exhibiting the highest grain yield per plant together with superior stover yield, panicle weight, plant height and 1000-seed weight. The strong positive association of panicle weight with grain yield at both phenotypic and genotypic levels further highlights its value as an indirect selection criterion. Collectively, these findings demonstrate that multi-parent-derived populations can serve as effective sources of favourable trait combinations and valuable breeding material for productivity improvement in post-rainy sorghum, complementing conventional hybrid development and heterotic-group-based breeding strategies.

6. Future Prospects

The promising entries identified in this study, particularly MC-28, warrant validation across diverse locations, seasons and representative post-rainy production environments to assess yield stability and genotype × environment interactions. Subsequent evaluation should integrate terminal drought tolerance, biotic-stress resistance, grain quality and key physiological traits governing post-rainy adaptation. Combining multi-environment phenotyping with molecular characterization, QTL mapping and genomic selection could further elucidate the genetic basis of favourable trait combinations generated through multi-parent recombination. Such integrated validation will establish the breeding value of MC-28 and other superior entries and support their targeted advancement as potential varieties or parental resources in future sorghum improvement programmes.

Author Contributions

T.V. conducted the experiments, contributed to data collection and analysis, and drafted the manuscript. S.B. and P.M. contributed to field experimentation and data collection. K.K.S. contributed scientific guidance. P.P. conceptualized the study, supervised the research, contributed to interpretation of the results, and critically reviewed the manuscript. T.V., S.B., P.M., P.P., K.K.S., & M.N.J. read and approved the final manuscript.

Competing Interests

The authors declare no competing interests.

Author abbreviations for the manuscript:

T.V. = Trupti Vhanamane[1]; S.B. = Sunil Bhusare[1]; M.N.J. = M. N. Jagtap[1]; P.M. = Priyanka Mashale[1]; K.K.S. = K. K. Sharma[2]; P.P. = Parashuram Patroti[2]*.

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